International Journal of General Engineering and Technology (IJGET)
ISSN(P): 2278-9928; ISSN(E): 2278-9936
Vol. 3, Issue 3, May 2014, 11-22
© IASET

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations
IASET

AN ALTERNATIVE METAL FOR STAINLESS STEEL USED IN FOOD INDUSTRY

ABDALWAHID K. BAKRI[1], KADHIM F. ALSULTANI[2] & SARA K. NAIF[3]

[1]Professor, College of Material Engineering, Babylon University, Babylon, Iraq
[2]Assistant Professor, College of Material Engineering, Babylon University, Babylon, Iraq
[3]Assistant Lecture, College of Material Engineering, Babylon University, Babylon, Iraq

ABSTRACT

The present research represents as an attempt to control corrosion rate of alloys, mainly stainless steel used in food industry. One way of controlling the corrosion rate, i.e. enhancing the effective life of this component is to alter all the factors affecting this rate.

However, the other way of enhancing the useful life is probably to find an alternative cheaper, nontoxic and available alternative. Results of this work proved that stainless iron can be used as a successful alternative for stainless steel used in food industry.

Tafel extrapolation corrosion test of these alloys in formic acid strongly supported this point.

Simple immersion corrosion test in formic acid of concentrations (20, 40 and 60% v/v) showed that corrosion rate of stainless iron was lower than stainless steel in several cases. If it was not so in certain tests then, it was found that heat treatment of stainless iron at (100°C) for (2 hrs) before corrosion test eliminate completely the difference in corrosion rate between them, and make the corrosion behavior of stainless iron even better. This treatment make stainless iron caused an increase of (800%) corrosion rate. Both stainless iron and stainless steel reached, in general, to a steady state after certain periods of time. A significant difference in corrosion rate between stainless iron and stainless steel was observed. For example an improvements in corrosion rate of (240% and 2100%) was found in formic acid at room temperature without preheating.

However, it's believed that, prior heat treatment of stainless iron enhanced the diffusivity of chromium atoms responsible of building the protective layer of (Cr_2O_3).

This why the preheating of this alloy during this work proved to be effective in accelerating the formation of chromia layer (Cr_2O_3). The reduction of corrosion rate of stainless iron reflected this result and even makes it lower than the corresponding value of stainless steel. It appears that even an increase of temperature from (40 to 65°C) caused a further reduction in corrosion rate of stainless iron compared to that of stainless steel in formic acid.

KEYWORDS: Corrosion Effect, Stainless Steels, Used in Food Industry

INTRODUCTION

Corrosion of metals and their alloys when exposed to the action of acids in industrial processes are recognized as major contributions to infrastructure deterioration [1]. The word corrosion is as old as the earth, but it has been known by different names. Corrosion is known commonly as rust, an undesirable phenomena which destroys the luster and beauty of objects and shortens their life [2]. Corrosion can defined as the destructive attack of metal by chemical or electrochemical reaction with its environments [3]. The aqueous corrosion of metals is generally considered an electrochemical action, that is, there are alternating sites of differing electrochemical activity on a metal surface, these sites act like anodes and cathode in a battery[4].

Also it can defined as the process of a metal returning to the material's thermodynamic state. For most materials, this means the formation of the oxides or sulfides from which they originally started when they were taken from the earth before being refined into useful engineering materials [5].

The serious consequences of the corrosion process have become a problem of worldwide significance [6]. Is a problem in a lot of industries and is even a greater challenge in the food processing and pharmaceutical industries, where in addition to the loss of production time for maintenance and risk of equipment failure, there exists the additional risk of product contamination by corrosion products which may result in food poisoning [7]. Organic acids are weak and non oxidizing. Those most commonly encountered are the mono carboxylic acids – formic, acetic, propionic, and butyric. In general, the corrosivity of these acids becomes weaker as the length of their carbon chain becomes longer. Thus, formic is most corrosive, followed by acetic, etc. As with other non-oxidizing acids, aeration and temperature usually increase corrosion [8].

Organic acids belong to the group of the most important chemical used in several industry such as texture, chemical and food, drug and pharmaceuticals. These acids are used as reagents for the manufacture of various chemicals ranging from drug and pharmaceuticals to plastic and fiber [9].

Corrosion is a normal, natural process. Corrosion can seldom be totally prevented, but it can be minimized or controlled by proper choice of material, design, coatings, and occasionally by changing the environment [10].

A variety of materials are being used for food processing, depending on the type of food and the processing conditions, such as temperature and pH values Stainless steels and aluminum alloys are the primary materials used in food processing [11]. The material selection is generally a balance between reliability and cost. For example, plain carbon steel which has been the most widely used structural material is abundantly available and is inexpensive, has adequate mechanical properties but has a high general corrosion rate particularly where water velocities are high [12]. It should be noted that the process of materials selection is not used solely to choose the material to build a structure or component. Rather, it is used to select a system of materials that together provide the necessary mechanical, thermal, electrical, and physical properties needed to meet performance requirements while simultaneously providing the necessary resistance to environmental attack including corrosion [13].

The development of alloys for controlling corrosion in specific aggressive environments is certainly one of the great metallurgical developments of the twentieth century [3].

When selecting a material of construction for a particular application, that material must have certain physical, mechanical, and corrosion-resistant properties. In the selection process, cost is also an important consideration. Although many alloys may be available to meet the criteria of the application, the cost of these alloys may be prohibitive. As a result, many coating and lining materials have been developed that can be applied to less expensive materials of construction to supply the necessary corrosion protection [5].

Stainless steel is an alloy of iron containing at least 12 per cent chromium. Chromium combines with oxygen in the surroundings to form an adherent chromium oxide film on the surface. This oxide film, also referred to as the passive layer, offers resistance to corrosion and will spontaneously self-repair when damaged in air or water. So the corrosion resistance is in the metal surface and the stability of the passive layer is therefore decisive to the corrosion resistance of the stainless steel [14].

EXPERIMENT WORK

Material Used

A two type of stainless steel set out and its chemical composition are shown in Table 1. Chemical analysis was done using a spectral analysis of metals in the General Company for Mechanical Industries in Alexandria.

Table 1: Illustrates the Percentages of Chemical Composition of Stainless Steel Used

Metals	.Composition %						
	C	Mo	Si	Cr	Ni	Mn	Fe
Stainless steel (A)	0.3	0.18	0.25	15	10	1.5	Balance
stainless iron (B)	0.10	0.2	0.2	20	1.5	0.5	Balance

Specimens Preparation

Preparations were carried out in full and including

Specimens cutting: samples are cutin two groups

Group 1: Disk shape with diameter (10mm) and thickness (2mm), this sample used in weight loss method and corrosion erosion test.

Group 2: Disk shape with diameter (14mm) and thickness (3mm), this sample used for Tafel test.

Surface preparation: its include grinding and polishing, grinding process occurs by using emery paper with gradually next (400, 800,1000,1200,2000 and 2500) then sample polishing by using alumina. After the end of each face samples were washed with distilled water and alcohol and dried with a stream of hot air; the weight of each sample was recorded using a sensitive balance type (Kern) Japan illustrated in figure (3-1), with an accuracy of (±0.1mg). After recording weights of samples they were placed in the portfolio to protect them from weather conditions.

Corrosion Test

Weight loss method: also called simple immersion method it is the simplest way of measuring the corrosion rate of a metal. In this method sample immersed in electrolyte solution for period of time.

In this work formic acid(CHOOH) was used which have different concentrations (20, 40 and 60% v/v) as electrolyte solution. Two types of steel stainless steel (A) and stainless iron (B) weighted before starting and record weight. The original weight $W_0$was measured and the surface area of each sample was calculated, then samples were immerse in electrolyte solution every (2 hr). After this time they were wished, dried and weighted. Then weights W_1 were also recorded by a sensitive balance. finally a plot of weight change per unite area ($\Delta W/A$) Vs time, was carried out.

Effect of Temperature

In this test effect of temperature on both metals stainless steel and stainless iron were investigated by using the water bath by simple immersion method. This test was carried out by immersed the sample in electrolyte solution (formic acid) at different concentrations (20, 40, and 60% v/v). Temperature in the range of (40 and 65 ℃) were adopted for several periods of time. Weights were measured by sensitive balance and the surface areas were calculated. The specimen were immersed in the electrolytic solution in the water bath at a certain temperature for (2hr). Then specimen was cleaned with water and alcohol, dried and measuring the weight. The change in weight per unite area were calculated and after by taking several readings results were represented graphically between the change weight per unit area and exposure time.

Tafel Examination

This test carried out in Babylon university college of material engineering by using potentiostat.

RESULTS AND DISCUSSIONS

Simple Immersion Test

Samples of stainless steel (A) and stainless iron (B) were immersed in formic acid of concentrations (20, 40 and 60% v/v) at room temperature. For different periods of time. The change in weight per unit area was recorded and plotted against time.

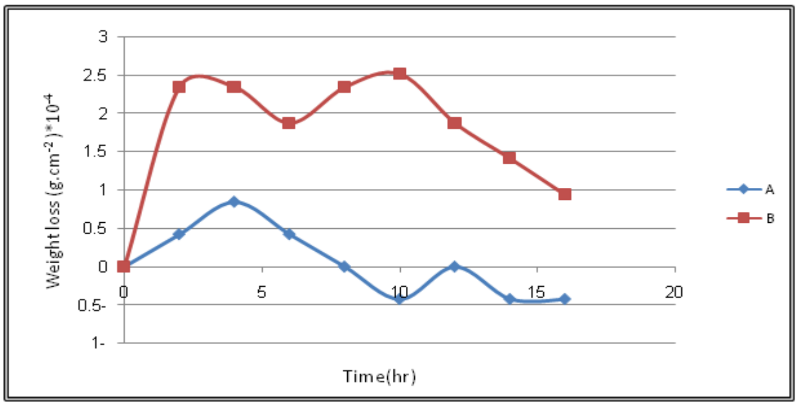


Figure 1: Illustrate the Effect of 20% V/V Formic Acid on Two Steels at Room Temperature Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni - 20 Cr)

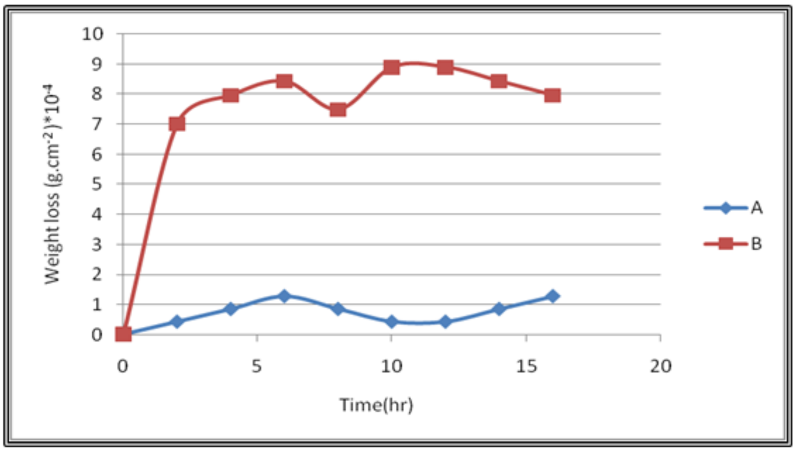


Figure 2: Illustrate the Effect of 40% v/v Formic Acid on Two Steels at Room Temperature Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni - 20 Cr)

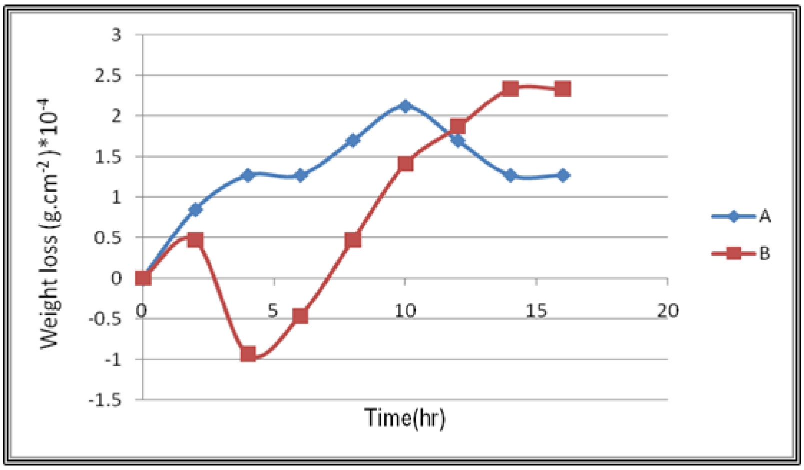


Figure 3: Illustrate the Effect of 60% v/v Formic Acid on Two Steels at Room Temperature Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni - 20 Cr)

Figure 1 shows the behavior of specimens in formic acid of concentration (20% v/v), both of them fluctuates in weight loss during the first (10hrs).

Stainless iron appears to exhibit reduction in weight loss after (10hrs) immersion while stainless steel tend to moves towards a steady state at almost (-0.5*10^{-4} g.cm^{-2}) weight loss.

However it since that stainless iron starts at lower loss rate than stainless steel within the first (10 hrs) when immersed in 40% v/v concentration of formic acid figure 2, after this period of time both samples slow a steady state weight loss.

When the concentration increased to 60%v/v figure 3 both specimens (stainless steel and stainless iron) behaviors in such a way that the weight loss is constant with time up to about (15 hrs).

We are looking for hopefully a possibility of an alternative for stainless steel in food industries; fortunately, the behavior of stainless iron apparently makes the suitable replacement and cheaper one.

The difference in weight loss between stainless steel and stainless iron observed specially in figure 3 can be explained and removed as flows, the weight loss shown in stainless steel curve can be attributed to the ability of chromia (Cr_2O_3) formed on stainless steel surface to protect it against corrosion.

The weight loss observed in the corresponding curve of stainless steel is higher; this is probably because the forming of (Cr_2O_3) is not as easy as in stainless steel. It takes time to be establishing .Once it's completed then it becomes protective and the weight loss almost independent of time as shown in figure 3

To prove this proposal, stainless iron was heated at (100 °C) for (2hrs) before immersed in formic acid. It clear from the figure 4 that a stainless iron behavior becomes even better than stainless steel and tends towards lower weight gain, stainless iron which is not heat treated remains nearly at the same rate of weight loss. This behavior is even more clear in figure 5; stainless iron (B heated) showed a much better behavior than both stainless steel and stainless iron (B not heated).

Stainless iron showed weight gain and after (11hrs) this tendency become very clear, the concentration in this case (20%v/v). Figure 6 conference this behavior.

As chromium is added to steel, a rapid reduction in corrosion rate is observed to around 10% because of the formation of this protective layer or passive film. In order to obtain a compact and continuous passive film, a chromium content of at least 11% is required [1].

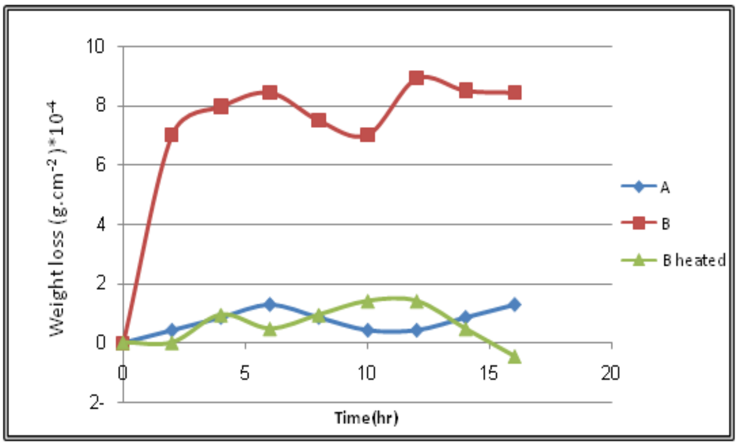


Figure 4: Illustrate the Behavior of (Metal B Heated) in Compare with A) Stainless Steel (10Ni-15Cr) and B) Stainless Iron (1.5Ni-20Cr) in 60% v/v Formic Acid at Room Temperature

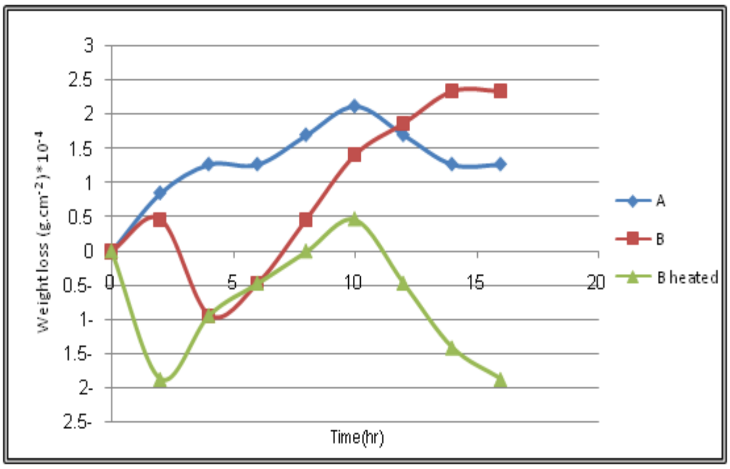


Figure 5: Illustrate the Behavior of (Metal B Heated) in Compare with A) Stainless Steel (10Ni-15Cr) and B) Stainless Iron (1.5Ni-20Cr) in 40% v/v Formic Acid at Room Temperature

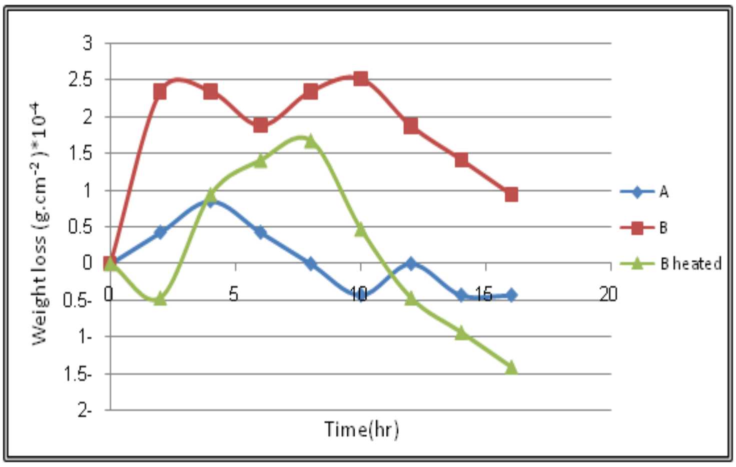


Figure 6: Illustrate the Behavior of (Metal B Heated) in Compare with A) Stainless Steel (10Ni-15Cr.) and B) Stainless Iron (1.5Ni- 20 Cr) in 20% v/v Formic Acid at Room Temperature

Effect of Temperature

This test occurs by immersed the sample in electrolyte solution (formic acid) at different concentration (20, 40, and 60% v/v) and also different temperature (40 and 65° C) for period of time, by using water path.

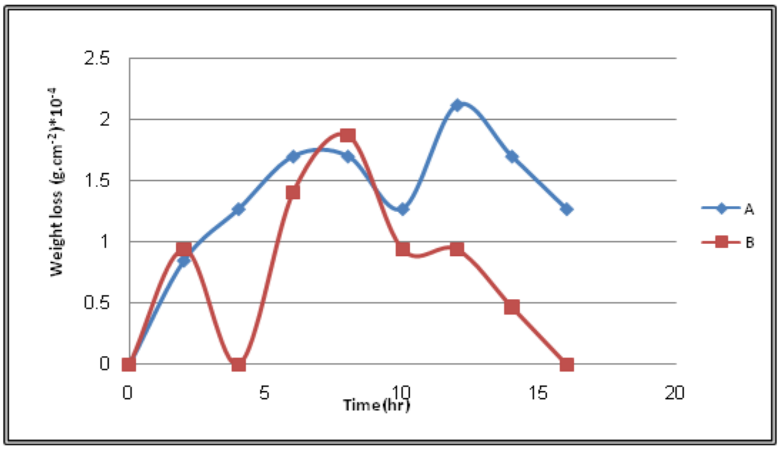


Figure 7: Illustrate the Effect of 40% v/v Formic Acid on Two Steels at 40 C Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni -20 Cr)

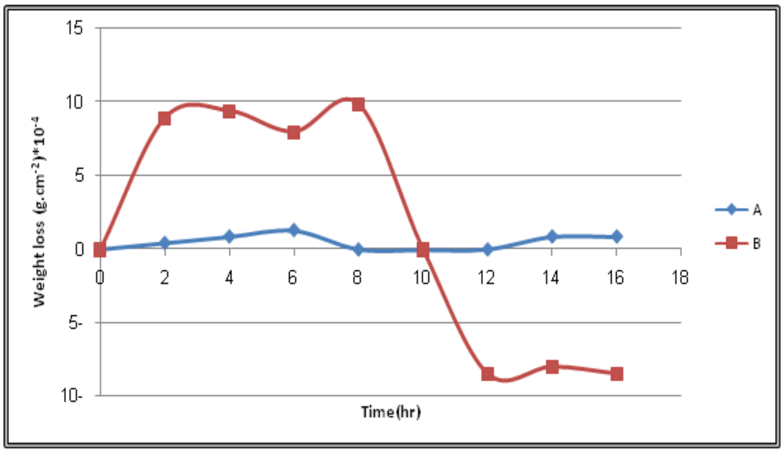


Figure 8: Illustrate the Effect of 40% v/v Formic Acid on Two Steels at 65 C Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni - 20 Cr)

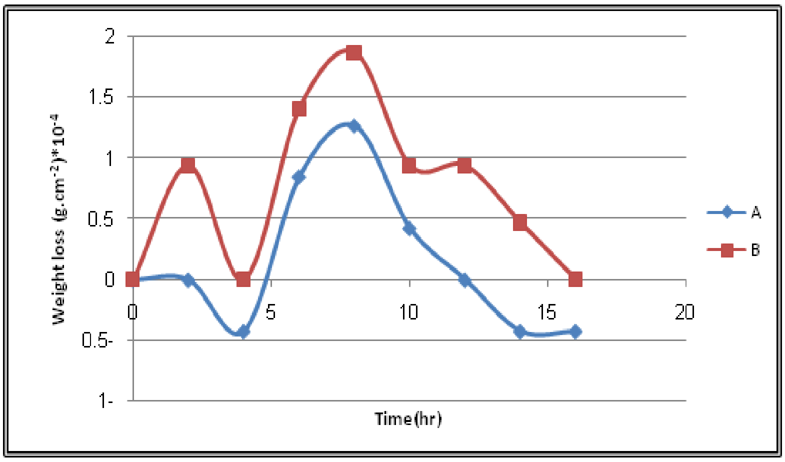


Figure 9: Illustrate the Effect of 20% v/v Formic Acid on Two Steels at 40 C where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni - 20 Cr)

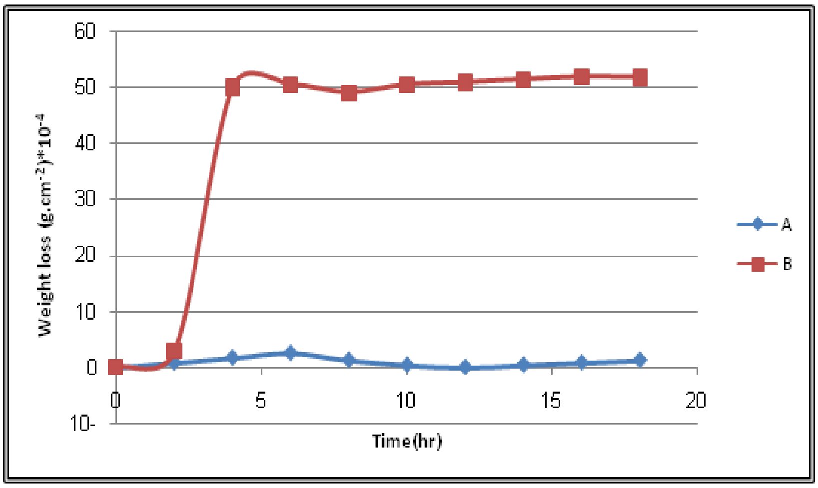


Figure 10: Illustrate the Effect of 20% v/v Formic Acid on Two Steels at 65 C Where A) Stainless Steel Contain (10 Ni -15 Cr) and B) Stainless Iron Contain (1.5 Ni -20 Cr)

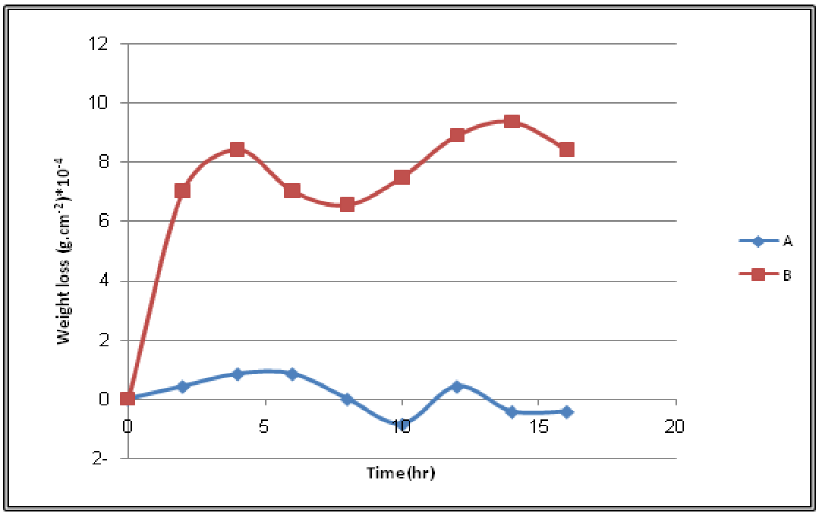


Figure 11: Illustrate the Effect of 60% v/v Formic Acid on Two Steels at 40 C Where A) Stainless Steel Contain (10 Ni -15 Cr) and B) Stainless Iron Contain (1.5 Ni -20Cr)

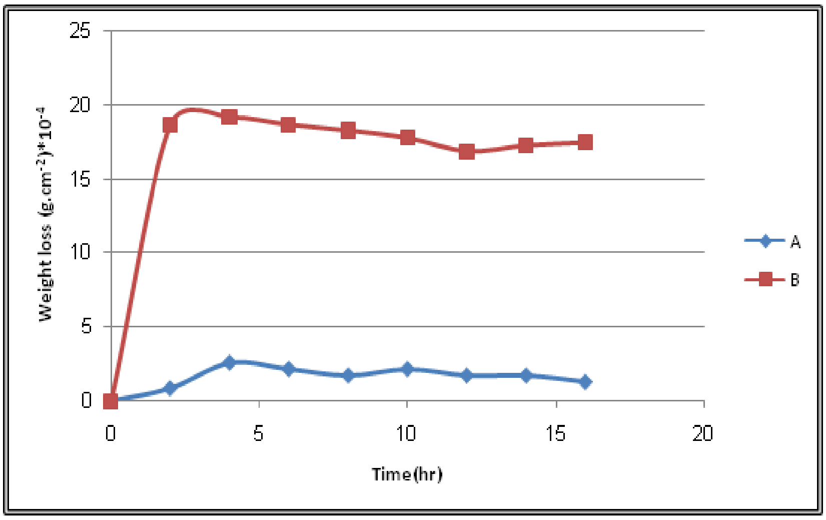
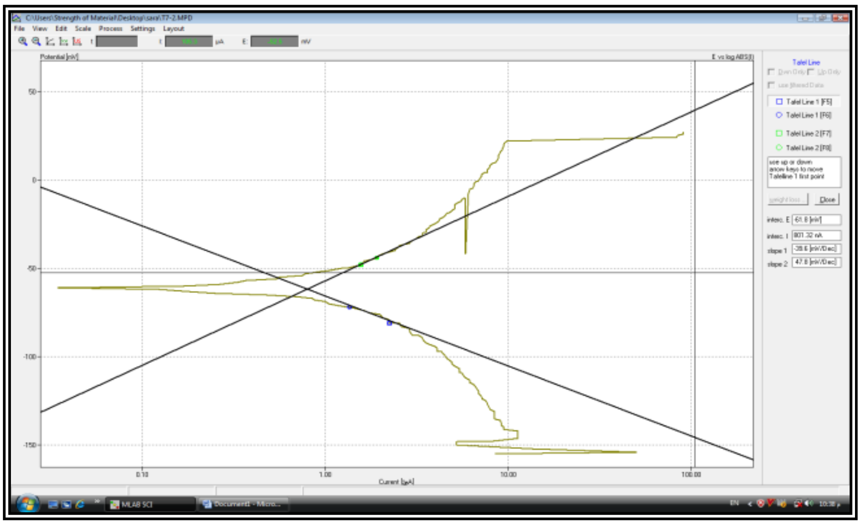


Figure 12: Illustrate the Effect of 60% v/v Formic Acid on Two Steels at 65 C Where A) Stainless Steel Contain (10 Ni - 15 Cr) and B) Stainless Iron Contain (1.5 Ni -20Cr)

Increasing immersion temperature of formic acid (40% v/v) makes the behavior of stainless iron better than corresponding sample of stainless steel. Corrosion rate of stainless iron move towards weight gain and steady state after about (10 hrs.) figure 7, this means a protective layer is built on this steel. When the temperature increased to (65 ° C) at the same concentration of acid, the corrosion rate of stainless iron at the beginning higher than corrosion rate of stainless steel and move towards weight gain figure 9. When the concentration of formic acid is reduced to (20% v/v) a similar behavior of both steels was observed figure10, at low temperature the difference is slight. But at higher temperature figure 11 it become steady state (independent of exposure time), stainless iron require time to build protective layer after which it corroded at constant rate.

A similar behavior is observed in figure 12 when the temperature was increase from (40 to 65 ° C) figure 13, stainless iron corrosion rate better than that of stainless steel because the temperature allow to faster diffusion of (Cr) to the surface and formation protective layer. This was associated with increase in corrosion rate. In both cases higher temperature is expected to enhance corrosion reactions.

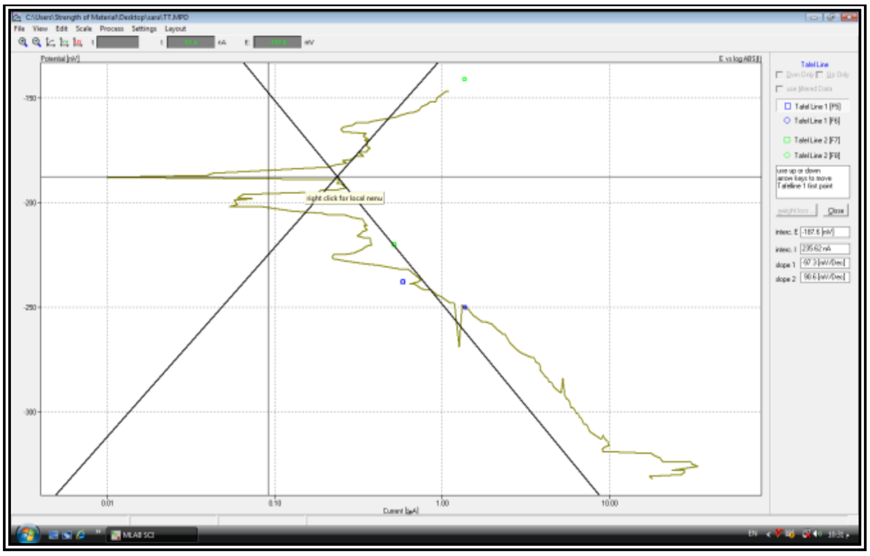
Tafel Test



use up or down arrow keys to move Tafelline 1 first point

intec. E -61.8 [mV]
intec. I 801.32 nA
slope 1 -38.6 [mV/Dec]
slope 2 47.8 [mV/Dec]

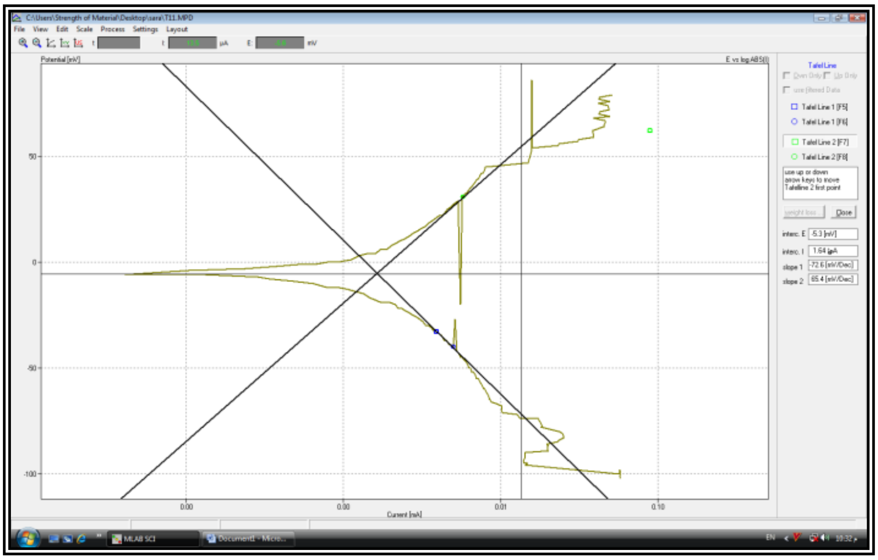
Figure 13: Polarization Curves for Stainless Steel (10 Ni - 15 Cr) Sample in 20% Formic Acid



use up or down arrow keys to move Tafelline 1 first point

intec. E -187.6 [mV]
intec. I 235.62 nA
slope 1 -97.3 [mV/Dec]
slope 2 90.6 [mV/Dec]

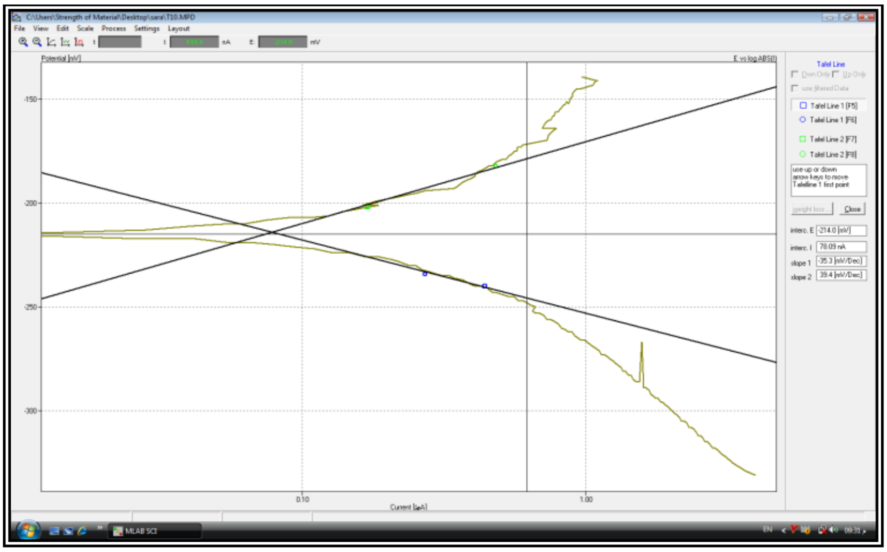
Figure 14: Polarization Curves for Stainless Iron (1.5 - 20 Ni Cr) Sample in 20% Formic Acid



use up or down arrow keys to move Tafelline 2 first point

interc. E -5.3 [mV]
interc. I 1.64 µA
slope 1 -72.6 [mV/Dec]
slope 2 65.4 [mV/Dec]

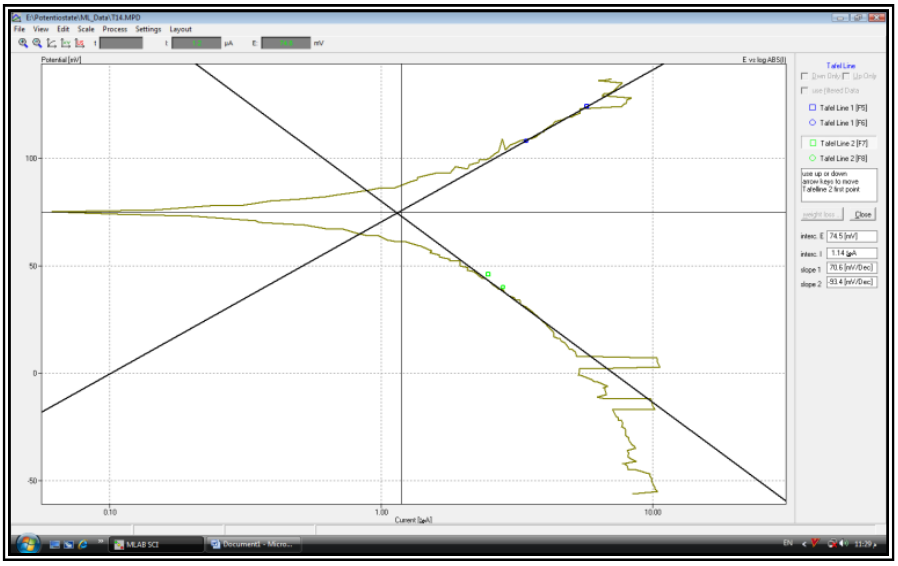
Figure 15: Polarization Curves for Stainless Steel (10 - 15 Ni Cr) Sample in 40% Formic Acid



use up or down arrow keys to move Tafelline 1 first point

interc. E -214.0 [mV]
interc. I 78.09 nA
slope 1 -35.3 [mV/Dec]
slope 2 39.4 [mV/Dec]

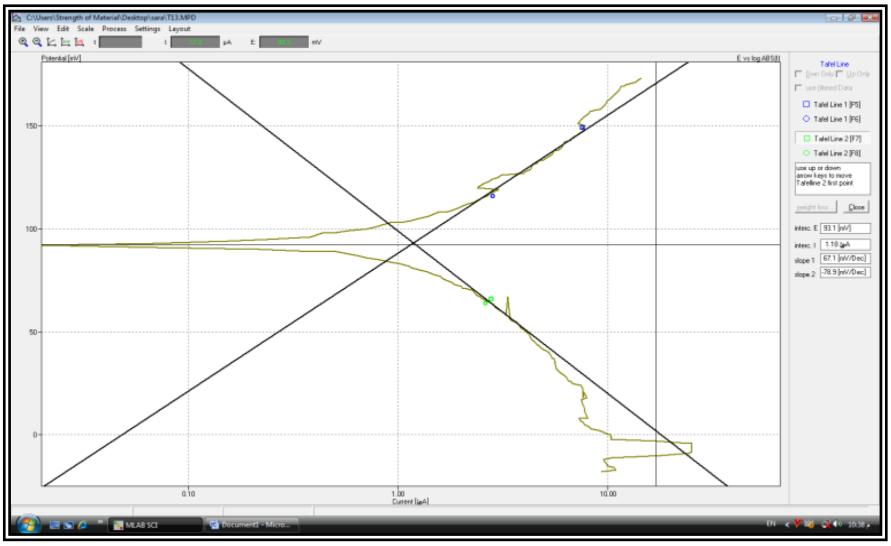
Figure 16: Polarization Curves for Stainless Iron (1.5 - 20 Ni Cr) Sample in 40% Formic Acid



use up or down arrow keys to move Tafelline 2 first point

interc. E 74.5 [mV]
interc. I 1.14 µA
slope 1 70.6 [mV/Dec]
slope 2 -93.4 [mV/Dec]

Figure 17: Polarization Curves for Stainless Steel (10 - 15 Ni Cr) Sample in 60% Formic Acid



C:\Users\Strength of Material\Desktop\sara\T13.MPD

use up or down
arrow keys to move
Tafelline 2 first point

intec. E 93.1 [mV]
intec. I 1.18 µA
slope 1 67.1 [mV/Dec]
slope 2 -78.9 [mV/Dec]

Figure 18: Polarization Curves for Stainless Iron (1.5 - 20 Ni Cr) Sample in 60% Formic Acid

Table 2: Illustrated the Corrosion Potential and Current Value of Two Metals in Formic Acid

Concentration %	Metals	
	Stainless steel	Stainless iron
20	E= -61.8 (mV) I= 801.32 nA	E= -187.6 (mV) I= 235.62 nA
40	E= -4.3 (mV) I= 1.64 µA	E= -214(mV) I= 78.09 nA
60	E= 74.5(mV) I= 1.14 µA	E= 93.1 (mV) I= 1.18 µA

From the figures 14 and 15which illustrated the anodic and cathodic polarization curves for two metals stainless steel (10Ni - 15Cr) and stainless iron (1.5 Ni - 20 Cr) in 20% v/v formic acid, we absorbed that the corrosion potential of stainless iron less negatives also the current value lower than is the case of stainless steel, this mean the corrosion rate stainless iron less than of stainless steel. Concentration in food industry are almost around (20%v/v). it appears that an improvement in corrosion of stainless iron is about (340%) comparing to the corresponding current of stainless steel. However, higher concentration were inspected to verify their possible harmful effects. At (40% v/v) improvement in corrosion current of stainless iron about(2100%) in compare with corrosion current of stainless steel figure 16 and 17. In very high concentration stainless iron proof to be neck to neck with a stainless steel (almost similar), figure 17 and 18.

CONCLUSIONS

It can be concluded from results of this research

- Controlling all factors affecting corrosion rate is surely one way to reduce the rate. However, finding a suitable alternate is another way of control. therefore a cheaper, nontoxic and available stainless iron can be used instead of stainless steel used in food industry as suggested by the results of this work.
- Tafel extrapolation corrosion test showed that reduction in corrosion current of (240%, 2100%) was observed in formic acid at room temperature without preheating for stainless iron.
- Preheating of stainless iron enhanced its corrosion resistance in such a way that it becomes even better than that of stainless steel.

- Corrosion behavior of both stainless steel and stainless iron reached, in general, a steady state after a period of time.
- Preheating of stainless iron eliminate any difference in corrosion current between stainless iron and stainless steel. Therefore, heat treatment of stainless iron caused an increase of (800%) in corrosion rate.
- Several evidences (tests) were cited in this work which indicate that stainless iron rates were lower even without preheating in both formic and acetic acids.

REFERENCES

1. SanusiKazeemOladele and Hussein Kehinde Okoro**," *Investigation of corrosion effect of mild steel on orangejuice*",** African Journal of Biotechnology Vol. 10 No.16, pp. 3152-3156, April 2011.
2. CEPHA Imaging Pvt. Ltd," ***Introduction to Corrosion*",** INDIA 2006.
3. Winston R. Revie and Herbert H. Uhlig, ***"Corrosion And corrosion control an introduction to corrosion science and engineering*"**, 4th ed, John Wiley & Sons, INC., 2008.
4. Roger A. Covert and Arthur H. Tuthill, ***" Stainless Steels: An Introduction to Their Metallurgy and Corrosion Resistance ",*** Dairy, Food Environmental Sanitation, Vol.20, No. 7, PP. 506-517, july 2000.
5. Philip A. Schweitzer**," *Fundamentals of Corrosion Mechanisms, Causes and Preventative Methods*"**, Taylor and Francis Group, LLC, 2010.
6. Pierre R. Roberge, "***Handbook Of Corrosion Engineering***", MC Grow – Hill companies, 2000.
7. Stanley U. Ofoegbu, Pearl U. Of oegbu, Simeon I. Neife and Boniface A., ***"Corrosion Behaviour of Steels in Nigerian Food Processing Environments",*** J. Appl. Sci. Environ. Manage Vol. 15, No. 1, pp 135 – 139, *March* 2011.
8. ***"High-Performance Alloys for Resistance to Aqueous Corrosion"*** , Special Metals group of companies, 2000**.**
9. Singh S. K., Mukherjee A. K. and Singh M., ***"Corrosion Behaviour of Mild Steel in Aqueous Acetic Acid Solution Containing Different Amount of Formic Acid Solution",*** Indian Journal of Chemical Technology, Vol. 18, pp 291-300, July 2011.
10. TCR Engineering Services Technical Team**," *Investigating Material and Component Failure*",** India, July 2004.
11. IvelisseTubens and Michiel P.H. Brongers**, *"FOOD PROCESSING",*** Technologies Laboratories, Inc., Dublin, Ohio.
12. Anees U. Malik, Ismail N. Andijani and Nadeem A. Siddiqi**, *"Corrosion Behavior of Some Conventional and High Alloy Stainless Steels in Gulf Sea Water"***
13. Benjamin D. Craig, Richard A. Lane, David H. Rose,***" Corrosion Prevention and Control: A Program Management Guide for Selecting Materials",*** Alion Science & Technology, 2006.
14. Foged, Jens Nielsen**,** Folkmar Andersen, Jepsen, Elisabeth and Melsing ***"Stainless Steel in The Food Industry"*,** Danish Technological Institute, 2005.